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DESIGN, DEVELOPMENT AND EXPERIMENTAL EVALUATION OF SOLAR DRYER

M. SAI KRISHNA TEJA[1], K. V. NARASIMHA RAO[2] & NITIN RALPH POCHONT[3]

[1]*Research Scholar, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India*

[2]*Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India*

[3]*Assistant Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India*

ABSTRACT

A solar dryer was designed, fabricated and installed at Energy Centre, KLEF (Deemed to be University), Vaddeswaram, Guntur District of Andhra Pradesh for drying of chili. The Solar dryer mainly consists of a solar collector, drying chamber and an electric blower. The chilies are dried under the present weather conditions and in a sophisticated solar cabinet dryer. Readings of temperature (at the collector inlet, collector outlet and dryer outlet (exhaust), relative humidity (at collector inlet, collector outlet and dryer outlet (exhaust), air flow rate and mass of chilies in grams (i. e. in lower tray, second tray and upper tray) respectively in hourly basis have been recorded during the experiment. The obtained values are compared with the Open sun drying.]The same weather conditions, it is observed that the chilies in the lower tray dried faster compared to the chilies kept in the remaining trays.

KEYWORDS: Solar Drying, Indirect Type Solar Dryer & Moisture Content

Nomenclature

A_c	*Collector Surface Area (m^2)*
c_{pa}	*Air specific heat (J/kg^0C)*
I	*Global solar radiation on the collector surface (W/m^2)*
A_c	*Collector Area*
L_c	*Length of collector*
W_c	*Width of collector*
N_t	*Number of tray*
A_t	*Area of each tray*
L_t	*Length of tray*
W_t	*Width of each tray*
M_f	*Mass flow rate*
V_{af}	*Volumetric air flow rate*
Q	*Collector useful heat energy gain*
Mr	*Moisture to be removed from the chili*
M_{fr}	*Instantaneous or final moisture of the product*

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Original Article

INTRODUCTION

In spite of being the first country to establish a ministry of non-conventional energy resources in 1980's, India is still backing huge energy issue. As a part of go-green campaign and global warming, it is our responsibility to investigate and understand the alternative sources of energy for the progress.

The country where agriculture holds the major economy, we pay less attention towards storage of the crop after harvest which is also a serious subject. Methods of preservation of food crops include canning, sugaring, salting, freezing, and dehydration, which might be an expensive affair to farmers in a country like India with a poor-framework for food storage.

If the production of renewable energy from the major renewable sources is not expensive, one can make best use out such abundant resources. So, one way of solving problem is to bring awareness among farmers in India and other Asian countries about the low-cost techniques and technologies that are beneficial in agriculture.

Solar energy is the abundant energy resource of the earth which can be used recurrently in such developing countries. Solar drying is one former technique used in drying the fruits, vegetables and agricultural food. Drying means moisture removal of the product. Drying preserves the food product for a long time and also it prevents the product from contamination.

The different types of solar drying are direct solar drying, indirect solar drying & mixed mode solar drying. In the initial days direct sun drying technique is popularly used, but there are some disadvantages such as:

- The time required for drying is more as compared to other methods.
- Output product quality is poor.
- The product obtained is contaminated by dirt, dust as well as by bacteria.
- Drying rate is poor in sun or natural drying.

To overcome this, indirect cabinet type of solar dryer is used for drying the different food products.

LITERATURE OVERVIEW

Sudhir et al. [1] conducted experiment on a cabinet type solar dryer with the different collector geometries and also conducted several experiments on potatoes, chilies and tomatoes. He got the average collector & system drying efficiency, overall efficiency of tomatos drying are found to be 39.06%, 6.89% respectively for flat plate, 42.97% & 8.95% for v shape, 42.76% & 8.88% of fin type collector. He has also illustrated that fin type collector has a highest average thermal efficiency of 46.15%, followed by v-groove type collector and flat plate type collector having average efficiencies 44.97%, 40.70% respectively. Solar dryer having a flat plate collector has a maximum average cabinet efficiency of 18.41% among other solar dryers with different collector plate.

While the cabinet efficiency of solar dryers having fin type collector plate and V grooved plate type collectors are found to be 17.38% and 16.49% respectively. Vaibhav et al. [2] Has designed & developed a solar cabinet dryer with thermal energy storage for drying chilies in June 2016. The capacity of the solar dryer is 15 kg. Vaibhav used paraffin wax

as a phase change material (PCM). The drying experimented is tested with the chilies and drying process is completed within 17 hours in the solar dryer for open drying it took around 27 hours.

Hussain et al. [3] Has designed & fabricated a solar dryer at Bogra, Bangladesh for drying of chili in February 2014. He has used a DC fan of 10 watts, which was used for exhausting moisture with the help of solar panel of 15 W. 8.75 kg dried chili was obtained from 30 kg of red ripe chili. The drying levels of red chili were obtained after 41 hours at upper tray and 46 hours at lower tray, but took 91 hours in the open sun drying system having same weather conditions.

Basumatuary et al. [4] Have worked for a low cost solar cabinet dryer as the main aim. Locally available materials are used in the experiment such as wooden flank, transparent glass or transparent thin plastic sheet, stainless steel net or bamboo net & GI sheet. The position of the tray was considered in such a way that the gap between each tray is ½ to 1/3 to that of the gap between lower most trays & bottom of the chamber.

Madhlopa et al. [5] Have designed and constructed a solar air heater with composite absorber systems for food dehydration during September 2001. The performance of the dryer was evaluated by drying fresh samples of mango. The Min components used are integrated flat plate collectors, collector absorber systems, several absorber plates, drying chamber & chimney. The main aim of the experiment is to reduce the moisture content and pH levels in fresh mangoes. The air heater achieved efficient drying of slices of fresh mangoes and a relatively high retention of ascorbic acid. The dehydrated fruits could therefore be preserved for consumption during the times of scarcity.

Mustafa Aktas et al. [6] Have done an analysis on drying of melon in a solar heat recovery assisted infrared dryer in August 2016. The infrared drying system is mainly popular for high heat & mass transfer. It is possible to catch fast heating and short drying time in comparison with other drying methods. The experiments were performed at 50–60^{0}C melons surface temperature. The material used are solar air collector, a heat recovery unit, drying cabinet, infrared lamps, K-type thermocouples (Range: 200 to 850^{0}C) and thermo-hygrometers. Here the analysis was done by theoretical calculations, energy balance and CFD analysis.

Halil Ataly et al. [7] modeled and developed a solar air heater to determine the drying rate of an apple. In order to provide the drying process continuously a packed bed thermal energy system was designed and manufactured. The range of temperature maintained is 40–60^{0}C. The materials used are two air collectors, drying cabinet, fans and respiratory unit. Performance of packed bed thermal energy storage system has predicted with the help of mathematical models. Finite difference methods are also used.

Varun et al. [8] constructed an indirect solar dryer, integrated with solar air heater and evaluated the dryer performance under natural and forced convection modes of drying. The main parts of the solar collector are absorber plate, cover plate & insulator. The absorber plate used is GI sheet painted with matt black and glass wool was used as an insulator. Wood has been chosen for the drying chamber since it is a poor conductor of heat, it has a smooth surface finish & heat loss by radiation is minimized. The performance study at no load and load are done. From his study of natural convection mode and forced convection mode, forced convection mode removes more moisture from the tomatoes as compared to natural convection. The overall efficiency of the drying chamber was found to be 17% and collector efficiency was found to be 30%. Amer et al. [9] Designed and constructed a hybrid solar dryer using direct solar energy and a heat exchanger. Hybrid dryers were developed to control the drying air condition throughout the drying time independent of sunshine, especially at night when it is not possible to use solar energy. The components used in the

experiment are solar collector, water tank, water pump, counter heat exchanger, drying chamber, blower (Axial type) and Auxiliary heater. Collector efficiency during day time, night time & solar dryer efficiency during night time was calculated. The efficiency of solar collector could be raised by recycling about 65% the drying air again in the solar dryer. The best condition for collecting solar energy during the day by the solar dryer is using the solar reflectors with the holders to move it according to sun angles during a day & by turning the dryer also according to sun angles.

Spain generates a big amount of agro industrial products of high moisture that produce a high environmental impact. Hence, Montero et al. [10] Have designed, constructed & performance test analysis of drying kinetics of these agro industrial by products and their possible power valuation. The most efficient operation mode will be forced hybrid followed by passive and active modes. The materials used are flat plate collector, drying chamber, galvanized iron chimney and additional air heating system. The analysis of the drying kinematics of the olive pomace shows better performance of the hybrid and mixed modes obtaining reductions of drying time of a 50% in both cases.

Abhay Lingayat et al. [11] have designed and developed an indirect type solar dryer for banana drying. The main objectives of this experiment are to conduct the drying experiments with sample products of bananas, to find the initial moisture content using a hot air oven to estimate the transient moisture content distribution, to estimate collector efficiency and dryer efficiency and to develop drying co relations. The components used in this experiment are flat plate collector (with V-shaped corrugated absorption plates) insulated drying chamber and chimney for exhaust air. From this study, the authors concluded that the Indirect type of solar drying is more effective than open sun drying as it reduced the drying time & the dried product is free from dust, environmental pollution etc.

Nabnean et al. [12] have designed and performed analysis for drying osmotically dehydrated cherry tomato in the solar dryer at Thailand. The main components used in this experiment are a water type solar collector, drying cabinet, cross flow heat exchanger and heat storage unit. The drying time for drying 100 kg of cherry tomatoes was found to be for 4 days. Colour change and composition analysis are the qualities of dried osmotically dehydrated cherry tomatoes.

Dilip Jain et al. [13] developed a state of the art solar crop dryer with thermal energy storage to maintain continuity of drying of herbs for their color & flavor vulnerability. The thermal energy storage is used for continuous drying and is provided with air heater. The dryer is attached with a packed bed thermal storage having a capacity of 50 kg PCM. The drying in such a manner that (PCM) phase change material stores the thermal energy during sunshine hours and release the latent heat and sensible heat after sunset. Thus the dryer is effectively operated for next 5-6 hours. The developed solar crop dryer is an alternative to overcome the disadvantages of traditional open sun drying and utilization of maximum available solar radiations.

Kamble et al. [14] have evaluated a solar cabinet dryer with gravel bed heat storage systems for drying of green chili. The loading capacity of the dryer was 15 kg. Drying time due to the introduction of heat storage system was extended by 4 hours after sunset. Drying efficiency of the solar cabinet dryer was found to be 34%. The drying time of the solar cabinet type dryer for reducing moisture content from 88.5% to 7.3% (wb) was found to be 86% less than open sun drying.

Bhanu Prakash et al. [15] investigations were mainly concerned with the performance analysis of solar drying system for Guntur red chili. Chili was dried to final moisture content of 9% wb from 80% wb in 24 hours using this system. After thoroughly studying the available literature, an indirect solar cabinet, type dryer is designed. The main objectives of the project investigation are:

To design and develop an experimental setup for indirect type cabinet solar dryer,

- To conduct the drying experiments with same food products such as grapes, red chilies etc
- To find the initial moisture content of red chilies & grapes
- To know the drying kinetics & dryer performance of the solar cabinet dryer.

DESIGN ASSUMPTIONS

A solar dryer was designed for chili drying and grape drying based on the procedure described [3] and for designing a collector by [1]. The following points are considered in the design of indirect type solar cabinet dryer. They are:

- The amount of moisture to be removed from a given quantity of wet chili.
- Harvesting period during which the drying is needed
- The quantity of air needed for drying.
- Daily solar radiation to determine energy received by the dryer per day.
- Wind speed for the calculation of air vent dimensions.

Design Assumptions of Solar Dryer

A solar dryer has to be designed, constructed and installed at Energy Centre, KLEF (Deemed to be University), Vijayawada for the analysis of drying kinetics of different agro-industrial byproducts and in different modes of operation. The solar cabinet dryer prototype, mainly consists of flat plate collector, drying chamber and an air blower. The following assumptions are made while designing the solar dryer.

Table 1: Design Assumptions

Parameter	Symbol	Value
Weight of fresh ripe chili	W_c	1 kg
Weight of fresh grapes	W_g	1 kg
Initial Moisture Content	M_i	75%
Final Moisture Content	M_c	8%
Wind Speed	V_w	3.5 m/s
Latent Heat of water	H_{fg}	2400 kJ/kg
Dryer temperature	T_d	50^0C
Drying time	T	24 hours
Spreading density	ρ_s	4 kg/m^2
Specific heat capacity of the product	C_p	3.81 kJ/kg

Moisture Content of Chili

The moisture content of the food product is expressed as percentage of moisture based on wet weight (wet basis) or dry matter (dry basis). Wet basis moisture content is generally used in commercial use. Dry basis is primarily used in research [16]

$$MC_{wb}\,(\text{wet basis}) = \frac{w_i - w_f}{w_i} \times 100$$

MC_{db} (dry basis) = $\frac{W_i - W_f}{W_f} \times 100$

Instantaneous or Final Moisture of the Product

The percentage of moisture content is obtained from the following relations [16]:

$M_d = M_p (1 - M_i/100)$

$M_d = M_{wf} (1 - M_{fr}/100)$

From the above relations, it can be concluded that

$M_f = 100 - 100Mp/M_{wf} (1 - M_i / 100)$

Where, M_d = mass of dry product (kg), Mp = initial mass of wet product (kg), Mwf = final mass of wet product (kg), Mi = initial moisture content (%), Mf = final moisture content (%).

Energy Requirement

The quantity of heat required to evaporate the H2O from chili would be:

$E = Mr \times h_{fg}$

The amount needed is a function of temperature and moisture content of the crop. The latent heat of vaporization was calculated using equation given by [3] as follows:

$H_{fg} = 4186 [597 - 0.56(T_{pr})]$

Collector Area

The collector was made for maximum utilization of solar energy. The black body material was used for increasing the efficiency of the collector. It is stated that the best slope (tilt angle) for the flat plate collector is equal to the latitude of the physical location. Still, the arrangement can be varied from 10^0 to 15^0 depending on applications in which, for space heating purpose (solar collector), latitude plus 10^0 is recommended for optimum solar radiation exposure during the summertime and a minus to the same degree during the winter.

Area collector, $A_c = E / (S_r \times \eta)$

Width of collector, $W_c = 1.5$ m (assuming)

Length of collector, $L_c = A_c / W_c$

Where, A_c = Collector area, (m2), E = Energy (kJ), S_r = Radiation, (kJ/m2), η = Efficiency, (%)

Drying Area

The drying chamber was built from the GI sheet which could withstand atmospheric attacks and economically available. The drying area was calculated by following equations.

Drying area, $Ad = M_p / \rho_s$

Number of trays, $N_t = 3$,

Area of each tray, $A_t = A_d / N_t$

Width of each tray, $W_t = A_t / L_t$

Where, L_t = Length of tray (m)

Length of tray (m)

Parts of Solar Drier

Solar Energy Collector

Solar collector consists of absorber plate, cover plate and insulation material. Any black materials can be heat observer. The solar collector is designed and constructed in such a way that it is air tight from two sides and passage between the bottom and top of the collector. It is rectangular in shape, where the lower layer is black insulated, second layer is an air passage medium and upper layer is transparent glass. It is raised a bit from the ground to allow the cold air to flow in and is kept at a certain inclination with respect to the reference ground. When the solar light is incident on the collector the air inside gets warm and pressure is also created low.

When the cold air gets into the heater, it gets warm and rises through the lower layer of shelves and exit from exhaust placed near the roof of the dryer. The air gets inside the collector due to the pressure difference between surrounding and the pressure inside of the dryer. Since the heater is raised at a certain angle, it is obvious that the hot air will pass through the passage to the top.

Drying Chamber

It is the main part of the dryer. Here the food products are being placed and get dried. It consists of trays made up of mild steel or stainless steel and the dried food products will be there after drying. It also consists of tiny holes for the passage of the warm air which is heated from the bottom. The dried air, then passes through the trays, and the food products inside the dryer get dried. This warm air will contain moisture when it reaches the top of the dryer.

Exhaust Air

The air having passed over the dried substances becomes saturated with water and is discharged through the exhaust to avoid condensation of water vapors in the event that the system temperature falls. If there is no air exhaust, vegetables and fruits may also decay. Therefore, it is necessary to have air exhaust.

Tray Load

The average tray carrying capacity of the dryer is estimated depending upon the food product and its mass.

Schematic of Solar Dryer

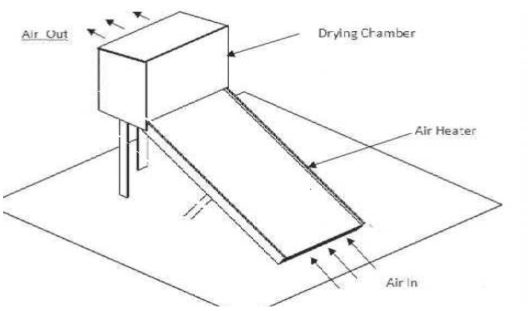

Figure 1: Schematic of Solar Dryer

Design Parameters of Solar Cabinet Dryer

Solar Collector

Solar collector with dimensions 700 mm × 350 mm × 50 mm, is made out of 1 mm thick GI sheet. The air gap between the absorber plate and the glass cover is 40 mm. The solar collector was inclined at an angle to receive maximum solar energy. Baffles are kept in the solar collector to increase more heat transfer rate. The material used for baffles is acrylic. The design parameters of the solar collector are given below.

Table 2: Parameters of Solar Collector

Parameter	Value
Area	0.245 m^2
Length	0.7 m
Width	0.35 m
Surface Treatment	Black Paint Coating
Absorber Plate	GI Sheet
Glass Cover	5 mm Thick glass
Insulation	Rock wool
Baffles	Acrylic

Figure 2: Actual Designed Solar Dyer

Absorber Plate

The absorber plate used in the solar collector is a GI sheet of 1 mm thickness, coated with black paint. The absorber plate was placed 40 mm below the cover plates to absorb incident solar radiation transmitted by the cover plates, thereby heating the air trapped between them.

Cover Plate

Ordinary glass plate with 5 mm thickness is used as cover plates over the absorber plate. The glass plates used here, also retarded heat from escaping, i. e. They form a confinement for heated air.

Insulator

The insulator is under absorber plate. An insulator is used here to minimize the heat losses from the system. Aluminium coated rock wool was used as an insulator in the present study. The thickness of the insulation was 25 mm.

Drying Chamber

The Drying chamber used here is made of GI sheet of dimensions 330 mm × 460 mm × 480 mm. Three drying trays of a size of 300 mm × 300 mm were used in drying chamber to accommodate the material to be dried. The design parameters of drying chamber are given below:

Table 3: Parameters of Drying Chamber

Parameters	Values
Length	330 mm
Width	460 mm
Height	480 mm
Type of Material (drying chamber)	GI sheet
No of drying trays	3
Type of material (drying tray)	Mesh type (Mild steel)
Tray size (l x b)	300 mm x 300 mm

(a) **(b)**

Figure 3(a & b): Pictures Showing the Number of Trays in the Dryer

INSTRUMENTATION AND MEASUREMENTS

Anemometer

An anemometer is a device used for measuring the speed of wind, and is also a common weather station instrument. The Anemometer used in the experimental work is Digital Anemometer Benetech GM816.

Figure 4: Anemometer

Hygrometer

Hygrometer is an instrument used for measuring relative humidity. The hygrometer, which was used in the project, is HTC -2 Digital Indoor / outdoor thermo hygrometer temperature humidity meter tester with time clock. It is has a pin type digital moisture measurer which measures the humidity inside a dryer.

Figure 5: Hygrometer

Temperature Indicator

Figure 6 shows the temperature indicator a device that shows the accumulated time, the temperature history of a product. From Figure 7, a K-type thermocouple is used which is the most common type of thermocouple. It's inexpensive, accurate, reliable, and has a wide temperature range. The type K is commonly found in nuclear applications because of its relative radiation hardness. The maximum continuous temperature is around 1,100C.

Figure 6: Temperature Indicator

Figure 7: Thermocouples

Experimental Procedure

The following steps constitute the Experimental procedure:

- Experiments were conducted to study the drying characteristics of chilies and grapes.
- The reduction in the moisture content was determined by weighing the sample at every hour.
- The chilies and grapes were spread uniformly on the three trays.
- The three trays were placed inside the drying chamber and the door of the dryer was closed properly
- Temperature, relative humidity, weight in grams and the size of the chilies and grapes are measured with respect to the drying time.
- Figure 8 shows the solar cabinet dryer and initial red chilies.

(a)

(b)

Figure 8: (a) Dryer (b) Red Chilies at Initial State

Observations of Chillies

The following observations are noticed while conducting the experiment. The observations are noted down for every hour from 9.00 am to 4.00 pm. Temperature, relative Humidity and mass of the chilies and grapes are noted as per tables below.

Temperature of Chillies

The temperature of the atmospheric, collector inlet, collector outlet & dryer outlet are measured by using a temperature indicator and K type thermocouple. K type thermocouple ranges from -270^{0}C to 1260^{0}C. Table 4 shows the temperatures of chilies.

Table 4: Temperatures of Chillies

S. No.	Time	Temperature (◦C)			
		Atmospheric Temp.	Collector Inlet	Collector Outlet	Dryer Outlet
1	9.00 am	35	35	35	35
2	10.00 am	36	40	42	43
3	11.00 am	37	42	44	45
4	12.00 pm	39	43	44	46
5	1.00 pm	41	48	49	50
6	2.00 pm	41	45	47	48
7	3.00 pm	40	44	46	47
8	4.00 pm	38	43	44	45

From table 4, it could be observed that the average temperature of the atmospheric, collector inlet, collector outlet and dryer outlet is 38.4^{0}C, 42.5^{0}C, 43.9^{0}C, 44.9^{0}C.

Relative Humidity Measurement of Chillies

The relative humidity is measured with a hygrometer for every one hour. The type of hygrometer we used in our project is HTC – 2 Digital Indoor / Outdoor thermo hygrometer temperature humidity meter tester with time clock.

Table 5: Relative Humidity Measurement of Chillies

S. No.	Time	Relative Humidity (%)			
		Atmospheric Humidity	Collector Inlet	Collector Outlet	Dryer Outlet
1	9.00 am	57	55	55	54
2	10.00 am	55	54	52	51
3	11.00 am	53	51	49	47
4	12.00 pm	51	47	43	42
5	1.00 pm	48	44	42	39
6	2.00 pm	45	41	38	36
7	3.00 pm	43	39	35	34
8	4.00 pm	41	38	34	33

Similarly, from table 5, it could be noticed that the average relative humidity of atmospheric, collector inlet, collector outlet and dryer outlet as 49.1%, 46.1%, 43.5% and 42%.

Mass (gm) of Chillies

The mass of the chilies (in grams) is noted down for every hour. The weight is measured by using a weighing balance. Table 6 shows the mass (gm) of chilies.

Table 6: Mass (gm) of Chillies

S. No.	Time	Mass (gm)			
		Lower Tray	Middle Tray	Upper Tray	Open Sun Drying
1	9.00 am	500	500	500	500
2	10.00 am	485	491	493	497
3	11.00 am	474	481	485	492
4	12.00 pm	462	471	478	487
5	1.00 pm	449	460	469	481
6	2.00 pm	435	448	459	477
7	3.00 pm	425	440	451	469
8	4.00 pm	412	429	442	462

From the above table (Table 6), it can be observed that more weight has been reduced in the lower tray when compared to middle tray, upper tray and open sun drying.

Observations of Grapes

The following observations are noticed while conducting the experiment. The observations are noted down for every hour from 9.00 am to 4.00 pm. Temperature, relative Humidity and mass of the grapes are noted as per below tables.

Temperature of Grapes

The temperature of the atmospheric, collector inlet, collector outlet & dryer outlet are measured by using a temperature indicator and K-type thermocouple. K type thermocouple ranges from -270^{0}C to 1260^{0}C. Table 7 shows temperatures of grapes.

Table 7: Temperatures of Grapes

S. No.	Time	Temperature (°C)			
		Atmospheric Temp.	Collector Inlet	Collector Outlet	Dryer Outlet
1	9.00 am	36	36	36	36
2	10.00 am	37	38	38	39
3	11.00 am	38	39	40	41
4	12.00 pm	38	40	41	42
5	1.00 pm	40	41	42	43
6	2.00 pm	41	42	43	44
7	3.00 pm	40	42	46	47
8	4.00 pm	38	43	46	48

From table 7, it could be observed that the average temperature of the atmospheric, collector inlet, collector outlet and dryer outlet is 38.5^{0}C, 40.1^{0}C, 41.8^{0}C and 42.5^{0}C.

Relative Humidity Measurement for Grapes

The relative humidity is measured with a hygrometer for every one hour. The type of hygrometer we used in our project is HTC – 2 Digital Indoor / Outdoor thermo hygrometer temperature humidity meter tester with time clock. Table 8 shows the relative humidity measurement of grapes.

Table 8: Relative Humidity Measurement of Grapes

S. No.	Time	Relative Humidity (%)			
		Atmospheric Humidity	Collector Inlet	Collector Outlet	Dryer Outlet
1	9.00 am	56	55	55	54
2	10.00 am	54	52	52	51
3	11.00 am	52	50	49	49
4	12.00 pm	46	44	43	42
5	1.00 pm	40	38	37	36
6	2.00 pm	39	36	35	34
7	3.00 pm	38	35	36	37
8	4.00 pm	37	34	35	36

Similarly, from table 8, it could be observed that the average relative humidity of atmospheric, collector inlet, collector outlet and dryer outlet are 45.3%, 43%, 42.8% and 42.4% respectively.

Mass (gm)

The mass of the chilies (in grams) is noted down for every hour. The weight is measured by using a weighing balance. Table 9 shows the mass (gm) of grapes.

Table 9: Mass (gm) of Grapes

S. No.	Time	Mass (gm)			
		Lower Tray	Middle Tray	Upper Tray	Open Sun Drying
1	9.00 am	200	200	200	200
2	10.00 am	196	197	198	199
3	11.00 am	193	195	196	198
4	12.00 pm	190	193	195	198
5	1.00 pm	186	191	193	196
6	2.00 pm	182	188	189	195

Table 9: Contd.,					
7	3.00 pm	179	186	187	193
8	4.00 pm	176	183	185	191

Here also from table 9, it could be observed that more weight has been reduced in lower tray when compared to the middle tray, upper tray and sun drying.

RESULTS & DISCUSSIONS

Initial Moisture Content for Chillies

The initial mass of red chilies & grapes (W_{wet}) and final mass of dried chilies & grapes (W_{dry}) was measured with the help of weighing balance. Initial moisture content was calculated by the following equation,

$$MC_{wb} = \frac{W_i - W_f}{W_i} \times 100 \qquad MC_{db} = \frac{W_i - W_f}{W_f} \times 100$$

Table 10: Shows the Moisture Content of Chillies

S. No.	Tray	Initial Mass of Chillies in gm	Size	Temperature◦ C)	Total Time (h)	Final Mass of Chillies in Grams	Moisture Content (W_{wet})	Moisture Content (W_{dry})
1	Lower tray	500	6 – 8 cm length	40–50 ◦C	35hrs	128	74.4	290.6
2	Second Tray	500				135	73	270.3
3	Upper Tray	500				149	70.2	235.5
Average		500				137.33	72.53	265.4

From the above table (Table 10), it can be concluded that,

- Red chilies possess 72.53% of moisture (water) approximately.
- The initial moisture content of chilies (wet basis) for lower tray, second tray and upper tray are found to be 74.4%, 73% & 70.2%
- The initial moisture content of chilies (dry basis) for lower tray, second tray and upper tray are found to be 290.6%, 270.3%, 235.5%.

Table 11: Shows the Moisture Content of Grapes

S. No.	Tray	Initial Mass of Grapes in gm	Size	Temperature, ◦C	Total Time (h)	Final Mass of Chillies in gm	Moisture Content (W_{wet})	Moisture Content (W_{dry})
1	Lower tray	200	3 cm length & 1.9 cm breadth	40 - 50°C	50hrs	41	79.5	387.804
2	Second Tray	200				56	72	257.14
3	Upper Tray	200				79	60.5	153.16
Average		200				58.66	70.66	266.03

Based on the observations of the above table (Table 11), it can be concluded that,

- Red chilies possess 72.53% and grapes possess 70.66% of moisture (water) approximately.
- The initial moisture content of chilies (wet basis) for lower tray, second tray and upper tray are found to be 74.4%, 73% & 70.2% whereas for grapes it was found to be 79.5%, 72% & 60.5%.
- The initial moisture content of chilies (dry basis) for lower tray, second tray & upper tray are found to be 290.6%, 270.3%, 235.5% whereas for grapes it was found to be 387.8%, 257.1% & 153.2%.

Variation of Solar Radiation, Air Temperature & Relative Humidity in Chillies

During the experiment, the variation of the relative humidity, temperature, weight of chilies and solar radiation were observed and plotted as shown in the below figures. Figures 9 and 10 shows the variation of relative humidity & temperature w.r.t. To time.

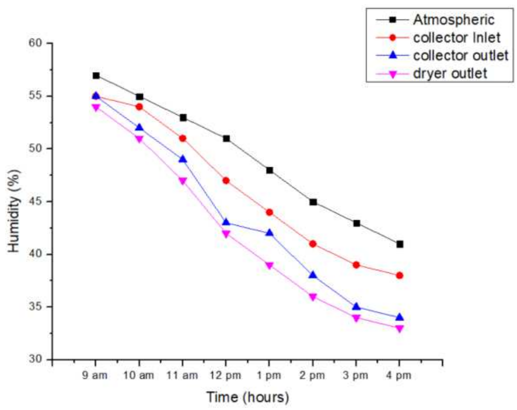

Figure 9: Variation of Time (h) vs RH (%)

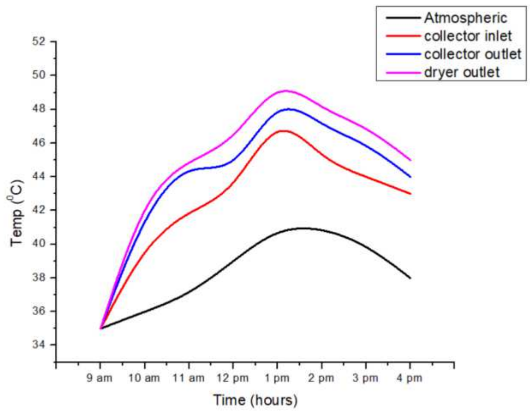

Figure 10: Variation of Time (h) vs Temp. (^{0}C)

From figure 9 the relative humidity of the atmosphere is higher when compared to the collector inlet, collector outlet & dryer outlet. The relative humidity is very low in the dryer when compared to atmospheric which is very important for higher drying rate as low, low humid air have more stability to absorb more moisture content. The average relative humidity of atmospheric, collector inlet, collector outlet and dryer outlet is 49.1%, 46.1%, 43.5% and 42%.

From Figure 10, daily mean values of atmospheric temperature, collector inlet temperature, collector outlet temperature and dryer outlet temperature are plotted and it was observed that dryer outlet temperature graph is high when compared to comparable outlet, collector inlet & atmospheric temperature. It was also observed that as the temperature rise when the air passes from the collector inlet to the dryer outlet. A maximum of 48^{0}C temperature was recorded in the dryer outlet where as the average atmospheric temperature is around 38.5^{0}C. Average temperatures of atmospheric, collector inlet, collector outlet and dryer outlet are observed as 38.4^{0}C, 42.5^{0}C, 43.9^{0}C and 44.9^{0}C.

Figures 11 and 12 show the variation of weight (gms) of chilies & solar radiation w.r.t time.

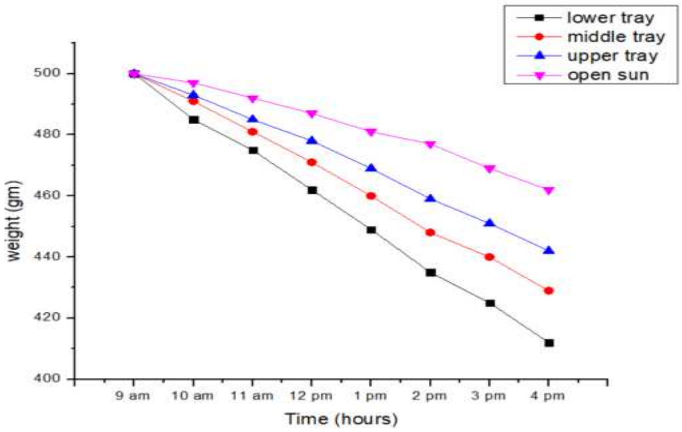

Figure 11: Variation of Time vs Weight (gm) of Chillies

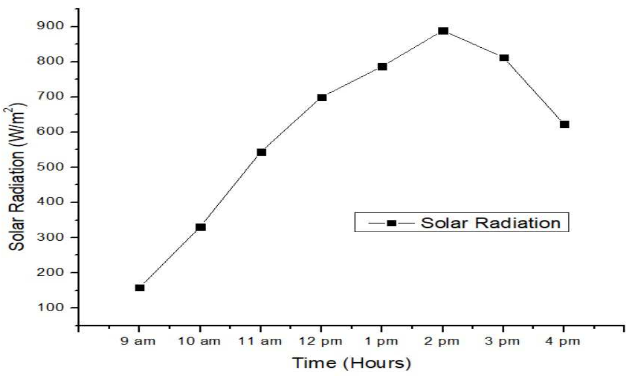

Figure 12: Variation of Time (h) vs Solar Radiation (W/m^2)

From Figure 11, it can be observed that more weight of chilies has been reduced in the lower tray when compared to the middle tray, upper tray & sun drying. Almost double the weight is reduced in the solar dryer when compared to natural sun drying. The total time taken for drying of chilies is 35 hours

From Figure 12, it can be concluded that the maximum solar radiation of 889 W/m^2 was noticed at 2.00 pm and the average solar radiation of 605.62 W/m^2 was noticed.

Variation of Solar Radiation, Air Temperature & Relative Humidity in Grapes

During the experiment, the variation of the relative humidity, temperature, weight of grapes and solar radiation were observed and plotted as shown in the below figures.

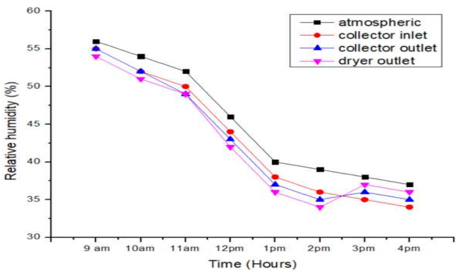

Figure 13: Variation of Time (hrs) vs RH (%)

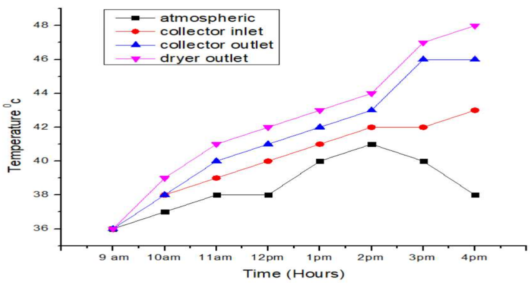

Figure 14: Variation of Time (h) vs Temp. (^{0}C)

From Figure 13, the relative humidity of the atmosphere is higher when compared to the collector inlet, collector outlet and dryer outlet. The relative humidity is very low in the dryer when compared to atmospheric which is very important for higher drying rate as low, low humidity air have more stability to absorb more moisture content. The average relative humidity of atmospheric, collector inlet, collector outlet and dryer outlet is 45.3%, 43%, 42.8%, 42.4%.

From Figure 14, daily mean values of atmospheric temperature, collector inlet temperature, collector outlet temperature and dryer outlet temperature are plotted and it was observed that dryer outlet temperature graph is high when compared to comparable outlet, collector inlet and atmospheric temperature. It was also observed that as the temperature rise when the air passes from the collector inlet to the dryer outlet. A maximum of 50^0C temperature was recorded in the dryer outlet where as the average atmospheric temperature is around 38^0C. Average temperatures of atmospheric, collector inlet, collector outlet and dryer outlet are observed as 38.5^0C, 40.2^0C, 41.8^0C, 42.5^0C.

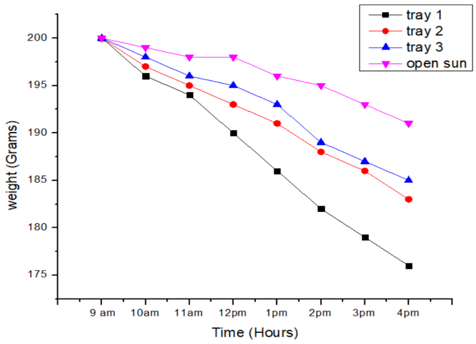

Figure 15: Variation of Time (h) vs Weight (gm) of Grapes

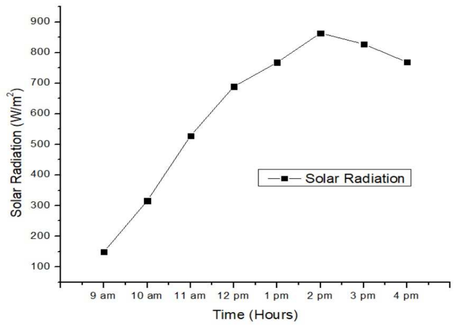

Figure 16: Variation of Time (h) vs SolarRadiation(w/m^2)

From Figure 15, it could be observed that higher weight of grapes has been reduced in the lower tray when compared to the middle tray, upper tray and sun drying. Almost double the weight is reduced in the solar dryer when compared to natural sun drying. The total time taken for drying of grapes is 50 hours.

From Figure 16, it is observed that the maximum solar radiation of 864 W/m^2 was noticed at 2.00 pm and the average solar radiation of 613.875 W/m^2.

Performance of the Dryer

The observations of chilies and grapes are taken in the month of April, May 2018 where higher temperatures are recorded of one hour interval. The average solar radiation was 605 W/m^2, ambient temperature was 38.4°C, ambient relative humidity was 45.3%, dryer inlet temperature was 43.9 and dryer outlet was 44.9^0C.

The solar radiation was very high from 12:00 pm to 2:00 pm. After 3:00 pm there was the cloudy environment, so the solar radiation diminishes significantly. The temperature in the dryer was significantly higher than that of the outside temperature from Figures 10 and 14.

The temperature of the lower tray is always low when compared to the second and upper tray. The temperature profile shows that dryer outlet temp>upper tray temp>second tray temp>lower tray temp > ambient temp.

CONCLUSIONS

Solar drier was designed and developed for drying red chilies and grapes with three trays. The drying rate of the upper tray chili was higher than that of the lower tray chili. In the case of chilies, upon drying for one day from 9 AM to 4 PM, the moisture content in the lower tray was reduced by 17.6%; moisture content has reduced by 14.2% in middle tray, and was reduced by 11.6% in the lower tray. It is also observed that the reduction of moisture content in open sun drying was only 7.6%. The moisture content in the chilies is decreasing linearly with drying time (approximately). The rate of decrease is more in case of lower tray and it is less in case of open sun drying, which is on expected lines. The temperature of the day was varying for a typical day and it is having maximum value hours of 11 AM to 4 PM. At this hour of operation dryer can get maximum solar radiation. Therefore, for a given humidity in the air, the dryer can have maximum efficiency.

Similarly for the grapes, the drying rate of upper tray was higher than that of lower tray. When compared to the chilies, the drying time of the grapes is high because the drying time of grapes is 50 hours whereas the drying time of chilies is 35 hours. It can also be concluded that for grapes the average temperature of atmospheric, collector inlet, collector outlet and dryer outlet are 38.5^0C, 40.2^0C, 41.8^0C, 42.5^0C which implies that the temperature is increasing gradually along with the air flow.

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